

# Modeling and Simulation of Wax Deposition in Crude Oil Pipeline

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## Abstract

As a fluid flows through a subsea pipeline, a cooling process occurs due to heat loss to the surrounding seawater. Wax may precipitate as a solid phase when the bulk temperature drops below the Wax Appearance Temperature (WAT), and wax can deposit on the pipe wall. Untreated wax deposition leads to reduced flow area, and to prevent blockage of the pipe a wax deposition model is used to predict the amount of wax to expect. Turbulent flow, single-phase experiments were performed with a waxy gas-condensate. The Hydro model, which takes into account asymptotic growth, seemed invalid for these experiments. The RRR and the Matzain model are available in the transient thermo hydraulic simulation software. Simulation studies have been carried out in order to find out the pressure and temperature drops in the pipeline under various operating scenarios and different ambient temperatures. Scenarios such as steady state flow (CTF Line / SRJ GGS), wax deposition and pigging, Skin Heat Tracing system (SHTS), alternate pumping of oil and water, higher dispatch temperature and additional line from field RRJ to field SRJ are developed. Results of wax deposition and pigging are discussed in this paper.

**Keywords:** crude oil pipeline, wax deposition, wax deposition model, transient thermo hydraulic simulation, Wax Deposition and Pigging

## Introduction

There are several wax deposition models with different approaches for modelling wax deposition.[1,2,3] In reality, the physical processes that constitute the wax deposition process are not properly discussed and the process of deposition is still poorly understood. Velocity determination applications such as gasification systems elaborate on momentum aspects in tubular lines. [4,5,6]

Most of the focus concerning formation and deposition of wax has been put on single-phase transportation of paraffinic oils, but significant problems with wax deposition may also occur in unstabilized oil and condensate systems.[7] An accurate prediction of wax deposition rates and deposited wax distribution in pipelines would represent high value for the industry. This information is valuable for the design stages of the field and also in the scheduling of intervention in the pipeline, in order to assure the oil flow at the desired rate.

In this paper, two wax deposition models are described. These are the RRR (Rygg, Rydahl and Rønningsen) model and the Matzain model. Simulations are carried out by using the RRR and the Matzain model, which are validated using transient simulator. The most important element is to illustrate how wax deposition models predict wax build-up.

## The RRR model

The RRR (Rygg, Rydahl and Rønningsen) model is a multi-phase flow wax deposition model which predicts wax deposition in wells and pipelines. Note that the RRR model is not applicable for laminar flow.[8] A standard steady state multi-phase point model is used to predict pressure drop and liquid hold-up along the pipeline. The effect of deposition on pressure drop and temperature is calculated by integration in time. The multi-component wax model continuously estimates the wax precipitation along the pipeline and the viscosity of the composition. The wax deposition is then estimated from the diffusion of wax from the bulk towards the surface of the pipeline, due to temperature gradients and shear dispersion effect. The inner pipe wall friction is varied due to wax deposition.[1,7,9,10]

The wax deposition model is divided into separate sub-models, where each sub-model describes specific technical aspect and the components are treated individually.[7,9,13]

## Sub-models:

- Flow model calculates pressure drop and flow regime
- Thermodynamic Wax Model (TWM) determines the number and properties of the different phases for each section
- Viscosity model calculates the viscosity
- Wax deposition model predicts the amount of wax that deposits in a section of the pipeline.

Wax deposition build-up is a slower process than flow disturbances in a pipeline. Therefore a semi-stationary model is chosen for wax deposition predictions over longer periods. Semi-stationary is described as changes in boundary conditions like flow rates, pressures and temperature are taken into account along with varying inner pipe diameter. The model is also compositional, meaning that all components are treated individually in each sub-model. A component mass balance is used for track keeping of all components.[7,10]

## Hydro model

The Hydro in-house wax deposition model was developed at Norsk Hydro by Søntvedt. [2,6] Hydro used the model a few times, but the model has never been reported or documented

officially. Previously this deposition model was implemented in an Excel spreadsheet, solved analytically and based on single-phase homogeneous flow. Today programming languages and simulators solve the governing equations numerically.[9, 14] The model is implemented in an in-house multiphase flow and heat transfer model, WellCorr.[11] The model estimates the amount of deposited wax over a time period inside a pipe, and it takes into account that deposition during time shows an asymptotic growth due to the stress from fluid flow. The model is based on theory of asymptotic fouling, which is known from the heat exchange theory. This theory is able to explain the asymptotic level of deposits seen in experiments.[11] Previous experiments performed at the wax rig in Porsgrunn used three different oils. This makes the model more robust when extrapolating to other oils.[11,13] The auto retardation mechanism is described mechanistically which is not based on tuning of a shear coefficient for shear removal. The deposit porosity is described mechanistically. This factor is a tuning parameter in other models. The Hydro model does not include shear dispersion. The Hayduk and Minhas correlation (1982) [12,13] is used for calculating the diffusion coefficient. The theory of fouling of heat exchanger equipment was suggested applicable for the mechanism of wax deposition in pipelines. Accumulation of deposit on a cold surface occurs due to mechanisms depending upon the fluid and the flow conditions.

### Methodology

The pipeline is discretized into a number of sections, where pressure and composition are assumed constant within one section. The temperature gradient reaches from the centre of the pipe to the pipe wall. The energy balance determines the bulk and wall temperatures. All sections are simulated, and independent pressure drops for each section are added up and gives the total pressure drop.[7,9]

Wax deposited in one period affects the results in the following time periods. Wax deposits in one section leads to decreased diameter, thus higher pressure drop in the pipeline. Additionally the energy balance is influenced, because the wax has an insulating effect in the pipeline. This results in increased temperature over time for a waxy section.[7,9]

Deposition in the RRR model is based on molecular diffusion and shear dispersion, both mechanisms which enhance the wax deposition. [7] The volume rate of wax deposition by molecular diffusion for a wax forming composition  $i$  is found from

$$Vol_{wax}^{diff} = \sum_{i=1}^{NWAX} \frac{D_i(c_i^b - c_i^w)S_{wet}MW_i}{\delta\rho_i} 2\pi rL \quad \text{Eq. 1}$$

Where  $c_i^b$  &  $c_i^w$  are the molar concentrations of the wax component  $i$  dissolved in the oil phase in the bulk and at the wall respectively (mole/m<sup>3</sup>),  $S_{wet}$  is the fraction of the wetted circumference,  $NWAX$  is the number of wax components,  $MW_i$  is the molar weight of wax component  $i$  (kg/mole),  $\rho_i$  is the density of wax component  $i$  (kg/m<sup>3</sup>),  $r$  is the current inner pipe radius (m) and  $L$  is the length of the pipe section (m).  $D$

is the diffusion coefficient, and the Hayduk-Minhas correlation (m<sup>2</sup>/s)[8] is used to calculate the diffusion coefficient.  $\delta$  is the thickness of the laminar sub-layer (m), and Blasius equation is used when calculating the thickness of the sub-layer in turbulent flow.[7]

Also the volume rate of wax deposited from shear dispersion can be estimated from a correlation by Burger et al. (1981)[15]

$$Vol_{wax}^{shear} = \frac{k^* C_{wall} \dot{\gamma} A}{\rho_{wax}} \quad \text{Eq. 2}$$

When accounting for both mechanisms, the total rate of increase in thickness for the wax layer is given as

$$l_{wax} = \frac{Vol_{wax}^{diff} + Vol_{wax}^{shear}}{(1-\phi)2\pi rL} \quad \text{Eq. 3}$$

Where  $\phi$  is the porosity of the deposited wax. The porosity is usually assumed to be in the range from 0.6-0.9. Wax layer porosity is an adjustable parameter in the model. Note that the thickness of the wax layer is averaged around the pipe circumference, even if the inner pipe surface is only partially wetted with liquid. For multi-phase flow the wetted inner surface area depends on the local flow regime predicted and the liquid hold-up. [7]

The RRR model has been applied to several single and multi-phase pipeline systems. In two cases presented by Rygg et al. (1998) [7], wax-build-up, temperature and pressure drops were simulated over time. Good agreement was shown between calculated and observed pressure losses. Important tuning parameters in this model are the wax layer porosity and the roughness of the wax deposit. [7,16,17,18]

An assumption made for this model is that the precipitation rate at the wall is not a limiting factor, and that all wax transported to the wall will stick to the surface as long as the temperature is below WAT.[19,20] It should be noticed that no removal mechanisms are discussed in this model. Therefore, the main drawback concerning the RRR model is the lack of shear incorporated into the model. However, the model may give good enough predictions for low flow rates.[21,22]

Additionally, this model may give reasonable predictions at the time when wax starts to grow at a clean pipe, but after some time the results become less reliable, due to no release-mechanism included in the model.

### Modeling the Process

#### Line pressure trend (RRJ-SRJ line)

Presently the production from RRJ field is about 500m<sup>3</sup>/d. The crude from RRJ is pumped to GGS-1. At RRJ GGS-1 the entire RRJ crude is heated to 55°C and pumped in RRJ-SRJ-CTF crude dispatch line. Due to viscous nature of RRJ crude high pressure drop is observed during winters in the RRJ-SRJ sector.

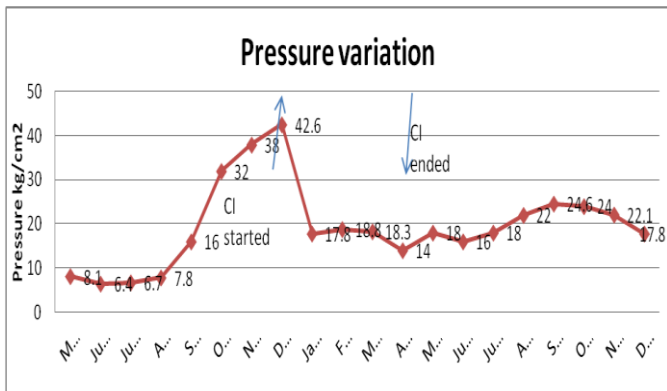


Fig. 1: Monthly pressure variation

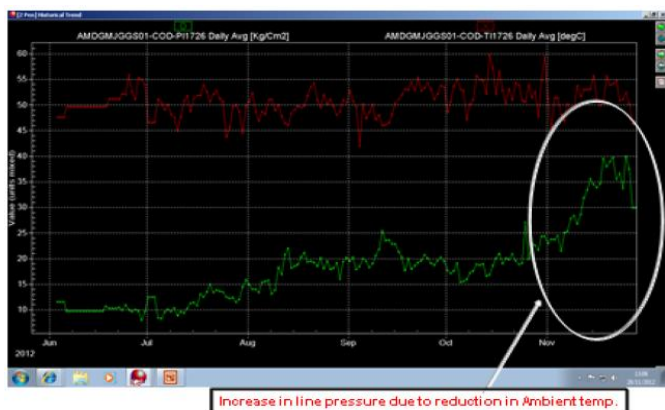


Fig. 2: Modelling of temperature and pressure parameters

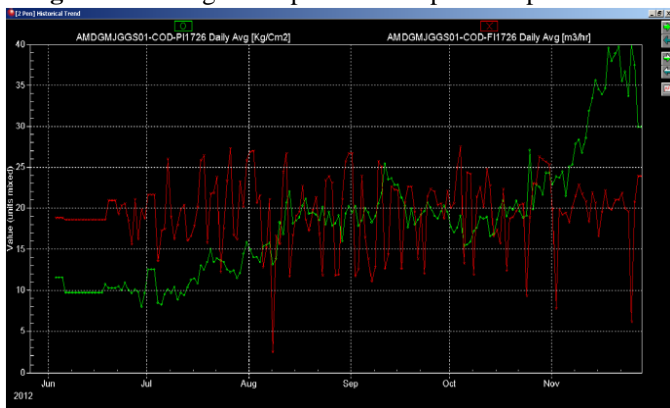


Fig. 3: Modelling of volume and pressure parameters

**Results of Simulation Studies for RRJ – SRJ line**

The RRJ SRJ sector is being pigged for scrapping of wax once in a month. Simulation has been carried out to predict the wax deposition possibility. The fluid modeling has been carried out to capture the fluid parameters. The simulation results representing winter conditions i.e. ambient 10°C are presented below.

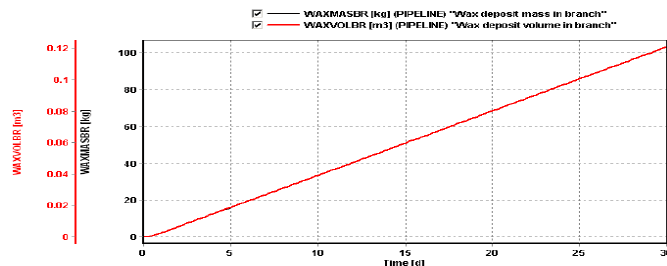


Fig. 4: Wax Mass vs Days

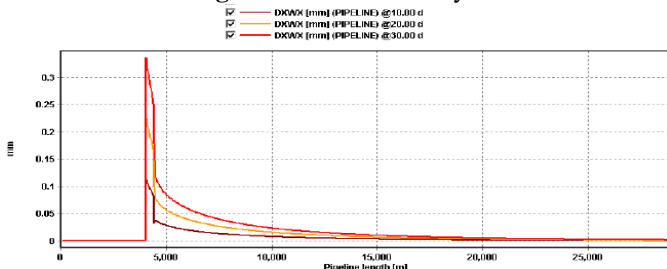


Fig. 5: Wax thickness along the line

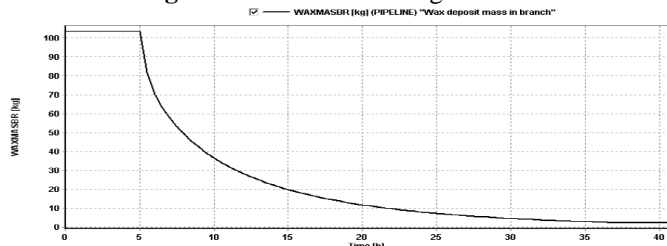


Fig. 6: Wax removal by pigging after 30 days deposition

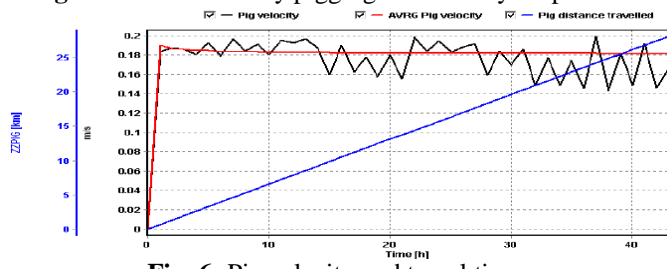


Fig. 6: Pig velocity and travel time

The crude parameters used for developing the simulation model are as follows:

Table 1: Crude properties used for simulation

No	Properties Value
1	Sp. Gravity 60/60°F 0.864-0.868
2	API Gravity 60°F 32
3	Pour Point (°C) 36-42
4	Viscosity Dry crude CP 363 @45°C, 300@ 25°C
5	Viscosity emulsion (50% w/c) CP 233 @45°C, 225@ 25°C
6	Viscosity emulsion (90% w/c) CP 233 @45°C, 437@ 25°C
7	STO(Wax) WT % 22-26

The pigging case simulation results for winter conditions i.e. ambient 10 deg C reveals the following results:

Table 2: The pigging case simulation results

No.	Particulars	Results
1	Wax deposition Mass in 30 days	~100 kg
2	Distance propensity from RRJ GGS-I	~ 5 kms
3	Peak thickness	0.3 mm
4	Average Pig Velocity	0.18 m/s
5	Pig travel time (RRJ GGS1-SRJ-GGS)	~41 hrs

## Conclusions

Wax deposition in pipelines represents a great challenge for the petroleum industry. By using wax deposition models, it is possible to predict the wax thickness and the pigging frequency can be estimated.

From the present study it is concluded that:

- High back pressure during winters in RRJ-SRJ and crude dispatch line is due to highly viscous crude
- Wax deposition (30 days) does not impact back pressure
- Pigging frequency of 30 days is found optimum
- Higher dispatch temperature, alternate oil-water pumping, diversion to intermediate tanks resulted in reduced back pressure

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